PLANT AND PROCESS FOR LIQUEFYING NATURAL GAS

FIELD OF THE INVENTION

The invention relates to novel plant and process for producing liquefied natural gas. The plant of the invention is of the type that comprises one natural gas pre-cooling heat exchanger having an inlet for natural gas and an outlet for cooled natural gas, optionally a distributor having an inlet connected to the outlet for cooled natural gas and having one or more outlets, and one or more main heat exchangers each comprising a first hot side having one inlet connected to one outlet of the distributor and an outlet for liquefied natural gas, which plant further comprises a pre-cooling refrigerant circuit for removing heat from the natural gas in the natural gas pre-cooling heat exchanger, and one or more main refrigerant circuits for removing heat from natural gas flowing through the first hot side of the corresponding main heat exchanger.

BACKGROUND OF THE INVENTION

US-P-4274849 and EP-A-0281821 disclose a process for liquefying a gas rich in methane, wherein the process utilizes two separate refrigeration cycles. Each cycle utilizes a multicomponent refrigerant. The low level (lower temperature) refrigerant cools and liquefies the natural gas in two stages by indirect heat exchange. The high level (higher temperature) refrigerant does not heat exchange with the natural gas to be liquefied, but cools the low level refrigerant by indirect heat exchange in an auxiliary heat exchanger.

US-P-6389844 discloses a plant of the type as disclosed above, in which the plant is such that the pre-cooling refrigerant circuit further comprises at least two additional circuits for removing heat from the main refrigerants in each of the main refrigerant circuits.

Such a plant, while it allows for a 40 to 60% increase of liquefaction capacity, still suffers from drawbacks. The liquefaction plant is still limited by the capacity of the propane compressor used in the pre-cooling refrigerant circuit.

The limited capacity of the propane compressor is still a problem for other usual plants. Solving this problem of limited capacity by the use of a pair of propane compressors in parallel on the same suction and discharge outlets is not satisfactory, since imbalanced load sharing and flow instability can then occur.

The invention aims at providing a novel plant and associated process for producing liquefied natural gas that is not limited by the propane compressor capacity.

SUMMARY OF THE INVENTION

The invention is based on the use of separate pre-cooling circuits: one for the pre-cooling of the natural gas and one for the pre-cooling of the main refrigerant.

The invention thus provides a plant as well as a process for liquefying natural gas.

In a first variant, the plant for liquefying natural gas comprises:

(i) one pre-cooling heat exchanger having an inlet for natural gas and an outlet for cooled natural gas;

(ii) one main heat exchanger comprising a first hot side having one inlet connected to the outlet of the heat exchanger and an outlet for liquefied natural gas;

(iii) one main refrigerant circuit for removing heat from natural gas flowing through the first hot side of the main heat exchanger;

(iv) a pre-cooling refrigerant circuit for removing heat from the natural gas in the pre-cooling heat exchanger;

and further comprises

(v) one additional circuit for removing heat from the main refrigerant in the main refrigerant circuit, where this circuit is separate from the pre-cooling refrigerant circuit for natural gas;

and wherein said main refrigerant circuit is separate from the pre-cooling refrigerant circuit.

In one embodiment, in the plant of the first variant, the additional circuit comprises a heat exchanger, a compressor, a cooler, and an expansion device, the compressor having an inlet and an outlet, said outlet being connected by means of a conduit to said cooler, said conduit extending via said expansion device to the inlet of the cold side of said heat exchanger, the outlet of the cold side of said heat exchanger being connected by means of a return conduit to the inlet of said compressor.

In this first variant, the process for liquefying natural gas comprises:

(i) pre-cooling natural gas in a pre-cooling heat exchanger into a flow of pre-cooled natural gas;

(ii) liquefying said pre-cooled gas flow in one heat exchanger comprising a first hot side having one inlet connected to the outlet of the heat exchanger for pre-cooled natural gas and an outlet for liquefied natural gas;

(iii) removing heat from the natural gas flowing through the first hot side of the main heat exchanger using a main refrigerant circuit;

(iv) removing heat from the natural gas in the pre-cooling heat exchanger for pre-cooled natural gas using a pre-cooling refrigerant circuit;

and further comprises

(v) removing heat from the main refrigerant in the main refrigerant circuit, in one additional circuit where the step of removing heat from the main refrigerants is separate from the step of removing heat from the natural gas in step (iv);

and wherein the step of removing heat from the natural gas in step (iv) does not make use of said main refrigerant circuit.

Said process is especially carried out in the plant of the first variant.

In a second variant, the plant for liquefying natural gas comprises:

(i) one pre-cooling heat exchanger having an inlet for natural gas and an outlet for cooled natural gas;

(ii) a distributor having an inlet connected to the outlet for cooled natural gas and having at least two outlets;

(iii) at least two main heat exchangers each comprising a first hot side having one inlet connected to one outlet of the distributor and an outlet for liquefied natural gas;

(iv) at least two main refrigerant circuits for removing heat from natural gas flowing through the first hot side of the corresponding main heat exchanger;

(v) a pre-cooling refrigerant circuit for removing heat from the natural gas in the pre-cooling heat exchanger;

and further comprises

(vi) at least two additional circuits for removing heat from the main refrigerants in each of the

main refrigerant circuits, where these circuits are separate from the pre-cooling refrigerant circuit for natural gas;

and wherein said main refrigerant circuits are separate from the pre-cooling refrigerant circuit.

In one embodiment, in the plant of the second variant, the circuits each comprise a heat exchanger, a compressor, a cooler, and an expansion device, the compressor having an inlet and an outlet, said outlet being connected by means of a conduit to said cooler, said conduit extending via said expansion device to the inlet of the cold side of said heat exchanger, the outlet of the cold side of said heat exchanger being connected by means of a return conduit to the inlet of said compressor.

In another embodiment, in the plant of the second variant, the circuits comprise each a heat exchanger and an expansion device, and further comprise one compressor and one cooler, the compressor having an inlet and an outlet, said outlet being connected by means of conduit to said one cooler, said conduit being divided into conduits connected via said expansion device, to the inlet of the cold side of said heat exchanger, the outlet of the cold side of said heat exchanger being connected by means of a return conduit to the inlet of said one compressor.

In yet another embodiment, in the plant of the second variant, the circuits comprise an integrated heat exchanger and an expansion device, and further comprise one compressor and one cooler, the compressor having an inlet and an outlet, said outlet being connected by means of conduit to said one cooler, said conduit being connected via said expansion device to the inlet of the cold side of said heat exchanger, the outlet of the cold side of said heat exchanger being connected by means of return conduit to the inlet of said one compressor.

In a preferred embodiment, the plant of the second variant comprises two main heat exchangers, two main refrigerant circuits and two additional circuits.

In this second variant, the process for liquefying natural gas comprises:

(i) pre-cooling natural gas in a pre-cooling heat exchanger into a flow of pre-cooled natural gas;

(ii) distributing said flow of pre-cooled natural gas into at least two distributed pre-cooled gas flows;

(iii) liquefying said at least two distributed pre-cooled gas flows in at least two main heat exchangers each comprising a first hot side having one inlet receiving one distributed pre-cooled gas flow and an outlet for liquefied natural gas;

(iv) removing heat from the natural gas flowing through the first hot side of the corresponding main heat exchanger using two main refrigerant circuits;

(v) removing heat from the natural gas in the pre-cooling heat exchanger using a pre-cooling refrigerant circuit;

and further comprising

(vi) removing heat from the main refrigerants in each of the main refrigerant circuits, in at least two additional circuits where the step of removing heat from the main refrigerants is separate from the step of removing heat from the natural gas in step (v);

and wherein the step of removing heat from the natural gas in step (iv) does not make use of said main refrigerant circuits.

Said process is especially carried out in the plant of the second variant.

In a further embodiment, in the plant of the invention, the first pre-cooling refrigerant circuit comprise a heat exchanger, a compressor, a cooler, and an expansion device, the compressor having an inlet and an

outlet, said outlet being connected by means of a conduit to said cooler, said conduit extending via said expansion device to the inlet of the cold side of said heat exchanger, the outlet of the cold side of said heat exchanger being connected by means of a return conduit to the inlet of said compressor.

In yet a further embodiment, the plant of the invention further comprises:

downstream said first pre-cooling heat exchanger, a pretreatment for removing part of the heavy components from the gas.

In yet a further embodiment, the process of the invention further comprises:

pretreating flow of pre-cooled natural gas for removing part of the heavy components from the gas.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows schematically the liquefaction plant according to the present invention;

FIG. 2 shows schematically another embodiment of the invention;

FIG. 3 shows schematically an alternative of the embodiment shown in FIG. 2;

FIG. 4 shows schematically a further alternative of the embodiment shown in FIG.2; and

FIG. 5 shows schematically a further alternative of the embodiment shown in FIG.2.

DETAILED DESCRIPTION OF THE INVENTION

Reference is made to FIG. **1**. The plant for liquefying natural gas according to the present invention comprises one natural gas pre-cooling heat exchanger **2**, a pre-cooling refrigerant circuit **3**, one main heat exchanger **5**, and one main refrigerant circuit **9**.

The natural gas pre-cooling heat exchanger **2** has a hot side in the form of tube **12** that has an inlet **13** for natural gas and an outlet **14** for cooled natural gas. The

tube **12** is arranged in the cold side or shell side **15** of the natural gas pre-cooling heat exchanger **2**.

The liquefaction heat exchanger **5** comprises a first hot side **25** having one inlet **26**. The inlet **26** of the first hot side **25** is connected to the outlet **14** of the heat exchanger **2**, by means of conduit **27**. The hot side **25** has an outlet **28** at the top of the liquefaction heat exchanger **5** for liquefied natural gas. The first hot side **25** is located in the cold side **29** of the liquefaction heat exchanger **5**, which cold side **29** has an outlet **30**.

The pre-cooling refrigerant circuit **3** comprises a turbine-driven pre-cooling refrigerant compressor **31** having an inlet **33** and an outlet **34**. The outlet **34** is connected by means of conduit **35** to a cooler **36**, which may be an air cooler or a water cooler. Conduit **35** extends via an expansion device in the form of a throttle **38** to the inlet **39** of the cold side **15** of the natural gas pre-cooling heat exchanger **2**. The outlet **40** of the cold side **15** is connected by means of return conduit **41** to the inlet **33** of the turbine-driven pre-cooling refrigerant compressor **31**.

In contrast with US-P-6389844, the pre-cooling refrigerant circuit **3** does only pre-cool the natural gas, and does not serve to pre-cool the refrigerant in the main refrigerant circuit **9** (and 9' as identified in said US-P-6389844). Also, the pre-cooling refrigerant circuit is separate from the main refrigerant circuit (9), in contrast with US-P-4274849 and EP-A-0281821.

To perform the pre-cooling in this main refrigerant circuit, the plant of the invention comprises one additional circuit **43**. The additional circuit **43** comprises a turbine-driven pre-cooling refrigerant compressor **131** having an inlet **133** and an outlet **134**. The outlet **134** is connected by means of conduit **135** to a cooler **136**, which may be an air cooler or a water cooler. Conduit **135** extends through conduit **144** via an expansion device in the form of a throttle **45** to the inlet **139** of the cold side 85 of the heat exchanger **58**. The outlet **140** of the cold side is connected by means of return conduit **146** to the inlet **133**

of the turbine-driven pre-cooling refrigerant compressor **131**.

The liquefaction refrigerant circuit **9** comprises a gas turbine-driven liquefaction refrigerant compressor **50** having an inlet **51** and an outlet **52**. The outlet **52** is connected by means of conduit **54** to a cooler **56**, which may be an air cooler or a water cooler, and the hot side **57** of a refrigerant heat exchanger **58** and to a separator **60**. The separator **60** has an outlet **61** for liquid at its lower end and an outlet **62** for gas at its upper end.

The liquefaction refrigerant circuit **9** further includes a first conduit **65** extending from the outlet **61** to the inlet of a second hot side **67** that extends to a mid point of the liquefaction heat exchanger **5**, a conduit **69**, an expansion device **70** and an injection nozzle **73**.

The liquefaction refrigerant circuit **9** further includes a second conduit **75** extending from the outlet **62** to the inlet of a third hot side **77** that extends to the top of the liquefaction heat exchanger **5**, a conduit **79**, an expansion device **80** and an injection nozzle **83**.

The refrigerant heat exchanger **58** includes a cold side **85** that is included in the additional circuit **43**.

During normal operation, natural gas is supplied to the inlet **13** of the hot side **14** of the natural gas pre-cooling heat exchanger **2** through conduit **90**. Pre-cooling refrigerant is removed from the outlet **40** of the cold side **15** of the natural gas pre-cooling heat exchanger **2**, compressed in the turbine-driven pre-cooling refrigerant compressor **31** to an elevated pressure, condensed in the condenser **36** and allowed to expand in the expansion device **38** to a low pressure. In the cold side **15** the expanded pre-cooling refrigerant is allowed to evaporate at the low pressure and in this way heat is removed from the natural gas.

Pre-cooled natural gas removed from the hot side **14** is passed to the heat exchanger **5**.

An optional pretreatment can also be contemplated in the invention, where the pretreatment unit **100** would be

located after heat exchanger **2**. Such a pretreatment unit would aim at withdrawing most part of the heavy components, typically part or all of the C2, C3, C4, C5 and heavier components of the gas. The resulting flow exiting from the pretreatment would comprise mostly methane. This flow will then be directed to the main heat exchanger **5**.

Through conduit **27** the pre-cooled natural gas is supplied to the inlets **26** of the first hot side **25** of the main heat exchanger **5**. In the first hot side **25** the natural gas is liquefied and sub-cooled. Sub-cooled natural gas is removed through conduit **95**. The sub-cooled natural gas is passed to a unit for further treating (not shown) and to tanks for storing the liquefied natural gas (not shown).

Main refrigerant is removed from the outlet **30** of the cold side **29** of the liquefaction heat exchanger **5**, connected through conduit **53** to inlet **51** of the turbine-driven liquefaction compressor **50**, where it is compressed to an elevated pressure. The heat of compression is removed in cooler **56** and further heat is removed from the main refrigerant in the refrigerant heat exchanger **58** to obtain partly condensed refrigerant. Partly condensed main refrigerant is then separated in separator **60** into a heavy, liquid fraction and a light, gaseous fraction, which fractions are further cooled in the second and the third hot side **67** and **77** respectively to obtain liquefied and sub-cooled fractions at elevated pressure. The sub-cooled refrigerants are then allowed to expand in expansion devices **70** and **80** to a lower pressure. At this pressure the refrigerant is allowed to evaporate in the cold side **29** of the liquefaction heat exchanger **5** to remove heat from the natural gas passing through the first cold side **25**.

In the above described embodiment, the refrigerant used in the pre-cooling circuits is suitably each time a single component refrigerant, such as propane, or a mixture of hydrocarbon components or another suitable refrigerant used in a compression cooling cycle or in an absorption cooling cycle. Preferably this pre-cooling refrigerant is propane. The main refrigerant is suitably a multi-component

refrigerant comprising nitrogen, methane, ethane, propane and butane.

The natural gas pre-cooling heat exchanger **2** comprises suitably a set of two or more heat exchangers arranged in series, wherein pre-cooling refrigerant is allowed to evaporate at one or more pressure levels. Suitably, the refrigerant heat exchanger **58** comprises a set of two or more heat exchangers arranged in series, wherein the pre-cooling refrigerant is allowed to evaporate at one or more pressure levels.

The main heat exchanger **5** can be of any suitable design, such as a spool wound heat exchanger or a plate-fin heat exchanger.

In the embodiment as described with reference to FIG. 1, the liquefaction heat exchanger **5** has a second and a third hot side, **67** and **77**, respectively. In an alternative embodiment, the liquefaction heat exchanger has only one hot side in which the second and the third hot side are combined. In this case the partly condensed main refrigerant is directly supplied to the third hot side **77**, **77'**, without separating it into a heavy, liquid fraction and a light, gaseous fraction. The liquefaction heat exchanger **5** can also be of any suitable design, as may be readily understood by the skilled man.

The compressors **31**, **50** and **131** can be multi-stage compressors with inter-cooling, or a combination of compressors in series with inter-cooling in between two compressors, or a combination of compressors in parallel (albeit this latter solution is not preferred).

Instead of turbines, electric motors can be used to drive the compressors **31**, **50** and **131** in the pre-cooling refrigerant circuit **3** and the main refrigerant circuit **9**, and the pre-cooling refrigerant circuit **43**.

The turbine (not shown) in the pre-cooling refrigerant circuit may be a steam turbine. In this case suitably, the steam required to drive the steam turbine is generated with heat released from cooling the exhaust of the gas turbines (not shown) of the main refrigerant circuits.

Reference is now made to FIG. 2, which shows schematically another embodiment of the invention. As one will immediately notice, the heat exchanger has been now duplicated (as in US-P-6389844). The plant for liquefying natural gas comprises one natural gas pre-cooling heat exchanger **2**, a pre-cooling refrigerant circuit **3**, a distributor **4**, and two main heat exchangers **5** and **5'**, and two main refrigerant circuits **9** and **9'**. For this FIG. 2, the second heat exchanger **5'**, and main refrigerant circuit **9'** comprise the same elements than the first heat exchanger and main refrigerant circuit, save that these parts are referenced with prime numbers. The pretreatment has not been shown in FIG. 2, as it is optional.

The distributor **4** has an inlet **18** connected by means of conduit **19** to the outlet **14** for cooled natural gas and two outlets **22** and **23**. Each liquefaction heat exchanger **5**, **5'** comprises a first hot side **25**, **25'** having one inlet **26**, **26'**. The inlet **26** of the first hot side **25** is connected to the outlet **22** of the distributor **4** and the inlet **26'** of the first hot side **25'** is connected to the outlet **23**, by means of conduits **27** and **27'**, respectively.

In one embodiment, the main refrigerant circuits **9** and **9'** are identical to each other and so are the main heat exchangers **5** and **5'**.

During normal operation, natural gas is supplied to the inlet **13** of the hot side **14** of the natural gas pre-cooling heat exchanger **2** through conduit **90**. Pre-cooled natural gas removed from the hot side **14** is passed to the distributor **4** through conduit **19**. Through conduits **27** and **27'** the pre-cooled natural gas is supplied to the inlets **26** and **26'** of the first hot sides **25** and **25'** of the main heat exchangers **5** and **5'**. The other operations are identical to the ones disclosed in relation with FIG. 1 (with one heat exchanger **5** and one main refrigerant circuit **9**). Hence, in the first hot side **25**, **25'** the natural gas is liquefied and sub-cooled. Sub-cooled natural gas is removed through conduits **95** and **95'**. In one embodiment, the amounts of

natural gas passing through conduits **27** and **27'** are equal to each other.

The liquefaction refrigerant circuits **9** and **9'** comprise refrigerants that may have the same composition. These circuits **9** and **9'** can, if desired, either be connected by a conduit (not shown) or even form one refrigerant circuit only.

In the embodiment of FIG. 2, each main refrigerant circuit **9** and **9'** comprises a complete pre-cooling circuit **43** and **43'**, where each pre-cooling circuit is identical to the one disclosed in FIG. 1.

Reference is now made to FIG. 3, which shows schematically another embodiment of the invention. As in FIG. 2, the plant comprises two main heat exchangers **5** and **5'**, and two main refrigerant circuits **9** and **9'**. In FIG. 3, the two additional circuits **43** and **43'** share the same compressor **131** and cooler **136**. A manifold **142** is connected at the outlet of the cooler to distribute the refrigerant to the expansion device (throttle **45** and **45'**) through conduits **143** and **143'**. The return conduits **146** and **146'** are connected to the inlet **133** of the compressor **131**, either directly or through a manifold (not shown).

In one embodiment, the compressors **31** and **131** (or optionally **131** and **131'**) can be driven by the same turbine.

Reference is now made to FIG. 4, which shows schematically an alternative of the pre-cooling refrigerant circuits **43** and **43'** as shown in FIG. 3. The refrigerant heat exchangers **58** and **58'** shown in FIG. 3 are combined in one integrated heat exchanger **202**. The integrated heat exchanger **202** has a cold side **215** in which are arranged the hot sides **57** and **57'** pertaining to the main refrigerant circuits **9** and **9'**, respectively. In this embodiment, the pre-cooling refrigerant is suitably a multi-component refrigerant comprising nitrogen, methane, ethane, propane and butane. During normal operation, evaporated pre-cooling

refrigerant is removed from the cold side **215** through conduit **241**, compressed to an elevated pressure by the pre-cooling refrigerant compressor **231** (having an inlet **233** and an outlet **234**), cooled in cooler **236** through conduit **235** and supplied to additional hot side **243** arranged in the cold side of the integrated heat exchanger **202**. In the additional hot side **243**, the pre-cooling refrigerant is liquefied against evaporating refrigerant. The liquefied pre-cooling refrigerant is removed from the additional hot side **243** through conduit **245** provided with expansion device in the form of throttle **246**, where it is allowed to expand to a lower pressure. At this lower pressure the refrigerant is supplied through injection nozzle **248** into the inlet of the cold side **215**.

Reference is made to FIG. 5 showing an alternative of the embodiment of FIG. 4, wherein the pre-cooling refrigerant compressor **231** is a two-stage compressor (having two inlets **233** and **233'** and an outlet **234**). The two-stage compressor **231** supplies refrigerant at elevated pressure to the additional hot side **243'** of the first stage integrated pre-cooling heat exchanger **202'**, wherein part of the refrigerant is allowed to evaporate at intermediate pressure in the cold side **215'**. The remainder is passed through conduit **250** to the additional hot side **243** of the second stage integrated pre-cooling heat exchanger **202**, this refrigerant is allowed to evaporate at low pressure in the cold side **215**. The inlets **233** and **233'** of the two-stage compressor **231** are connected to the cold sides **215** and **215'** of the heat exchangers **202** and **202'** by conduits **241** and **241'**, respectively. In the first and second stage heat exchangers **202** and **202'** the liquefaction refrigerant of each of the liquefaction refrigerant circuits is pre-cooled in hot sides **57** and **57'**. For the sake of clarity the conduits interconnecting the latter hot sides have not been shown.

It would also be possible to have one compressor only, with two coolers for each circuit, a manifold being this time arranged at the outlet of the compressor to distribute the refrigerant to each cooler.

The pre-cooling refrigerant circuits in the invention are separate. The ratio of compression power between the pre-cooling circuit **3** and the additional circuit **43** (**43** and **43'** if and when present) is for example from 15:85 to 40:60, typically about 25:75.

An advantage of the present invention is that the conditions of pre-cooling and liquefaction, for example the compositions of the refrigerant, can easily be adapted such that an efficient operation is achieved. Moreover, in case one of the liquefaction circuits has to be taken out of operation, the conditions can be adapted to work efficiently with a single liquefaction train.